Penobscot River Modeling Report
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Executive Summary

1. A study of the Penobscot River from Millinocket to Bucksport (103 miles) began in the summer of 1997 involving the DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, Champion International, USEPA, and a coalition of point source dischargers named the Penobscot River Basin Discharger's Council.

2. Data was collected from August 5 to 7 to calibrate a water quality model. The lack of runoff three weeks prior to the survey, presence of low flow conditions (about 5 year low flow and 97% flow duration), and utilization of good QA/QC measures resulted in excellent quality data to calibrate the water quality model. In addition, single day surveys were undertaken at five different times over the summer to assess overall water quality conditions, and whether or not D.O. readings met minimum statutory criteria.

3. Non-attainment of class B D.O. criteria was observed at one location (North Lincoln) where readings were within 0.3 ppm of minimum class B DO criteria of 7 ppm. Moderately elevated algae readings as chlorophyll a (6 – 10 ppb) were observed above Dolby and Weldon dams on the West Branch and in the estuary at Fort Knox. For detailed descriptions of the data, one should consult the Penobscot River Data Report (MDEP, April 1998).

4. The EPA supported model QUAL2EU, adapted to model estuaries (QUAL2EST), was utilized to simulate water quality conditions on the Penobscot. The current model updates prior efforts undertaken in 1985 and 1991. The current model merges three "submodels" of the Penobscot and West Branch so that the Penobscot is now represented as one continuous model from Millinocket to Bucksport.

5. The model was re-calibrated with the data collected on August 5-7, 1997. Only minor adjustments to prior model assumptions were necessary. An additional improvement made to the model is the simulation of nutrients and chlorophyll a.

6. The re-calibrated model resulted in a good fit to the observed BOD, dissolved oxygen, and chlorophyll a data, except that the model's prediction of chlorophyll a was low on some of the impoundments of the West Branch. Additional work is needed in the future to better calibrate the algae component of the model.

7. The model run at worse case conditions of 7-day-10-year low flow (7Q10), high water temperatures, and point sources at licensed loads predicts that dissolved oxygen criteria will be met everywhere on the Penobscot except an 8 mile segment from Winn to North Lincoln. This problem is not considered serious, since the model predicts that the river here is within 0.4 ppm of minimum class B dissolved oxygen criteria of 7 ppm. From a regulatory perspective cleanup action is needed. The model also predict marginal attainment of minimum dissolved oxygen criteria for a

8. five-mile segment from the West Enfield dam to Passadumkeag and a one-mile segment at the end of the tidal river in Orrington.
9. A component analysis was undertaken at three strategic points on the river to determine the causes of dissolved oxygen depletion. The following causes were determined to be the most significant
   Above Rockabema Dam – Sediment Oxygen Demand (38%) and Background (32%)
   Winn – Sediment Oxygen Demand (35%) and Nutrients (28%)
   Orrington – Sediment Oxygen Demand (38%) and Point Source BOD (35%)

10. The largest source of nutrients loads to the Penobscot are the Great Northern Mills in Millinocket and East Millinocket, which collectively account for about 70% of the total phosphorus of the upper Penobscot; and the city of Bangor which accounts for about 50% and 60%, respectively of the total phosphorus and total dissolved nitrogen of the lower Penobscot River and estuary.

11. There is very little, if any, assimilative capacity left in the Penobscot River. For this reason, the following actions are recommended:

• Voluntary pollution prevention measures to reduce phosphorus discharges from the Great Northern Paper Mills.

• Voluntary pollution prevention measures by all other point source discharges to reduce phosphorus in the non-tidal river and nitrogen in the tidal river.

• Collection of an additional data set in the summer of 2001 that will be used as a verification data set for the water quality model.

• Collection of sediment oxygen demand (SOD) data and assessment of source of SOD.

• After data collection in the summer of 2001, re-assessment of attainment / non-attainment status of dissolved oxygen criteria and the trophic state of the Penobscot River.

• Completion of the water quality model with new data including more emphasis on the algae and nutrient component.

• After data collection and model completion, re-assessment of the need for mandatory BOD or nutrient controls.

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Introduction

The Penobscot River Basin is the largest river basin lying entirely within the state of Maine. It has a drainage area of 8592 square miles at its mouth. The river segment of interest on the Penobscot River begins in Millinocket below Ferguson Lake as the West Branch, where after 10 miles it joins with the East Branch. It then flows an additional 72 miles before reaching head of tide at the breached Bangor dam, and then over 21 additional miles of tidal waters to Bucksport. In this 103 mile segment, there are 15 point source discharges, 12 dams, 11 of which are retrofitted for hydropower, and 9 tributaries that have a drainage area of over 100 square miles. A list of dams and point sources are illustrated in tables 1 and 2.

The Penobscot River Data Report (April 1998, MDEP) discusses the data that were collected by DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, Champion International, USEPA, and a coalition of point source dischargers, the Penobscot River Basin Dischargers Council, in the summer of 1997. The data were collected to gather updated information on the river from the information collected 12 years prior and to update a water quality model that was previously developed by MDEP in 1991. This report discusses the modeling undertaken by DEP as a follow up to the 1997 sampling effort.

Summary of 1997 Data

The overall quality of the 1997 data are considered excellent due to good QC measures utilized throughout the sampling effort that involved such practices as cross checking of dissolved oxygen meters and duplicate sampling. The three-day intensive survey undertaken on August 5,6, and 7 of 1997 is specifically for re-calibration of the water quality model. It is desirable to collect the model calibration data sets under conditions of low flow and high water temperature. This represents conditions of worse case when river dissolved oxygen levels are most likely to be the lowest. At lower river flows, the dilution of pollutant waste loads is reduced resulting in river pollutant concentrations of higher strength. At high water temperatures, dissolved oxygen saturation decreases and the biological activity increases resulting in a greater amount of oxygen demand in the water column as BOD (biochemical oxygen demand) and greater amount of oxygen demand from bottom sediments (SOD). Thus water column dissolved oxygen depletion is maximized under these conditions.

A goal of sampling less than 4400 cfs at the USGS gage in West Enfield (90% flow duration) was used as a target flow for the three-day intensive survey. This goal was met, since the flow was 3620 cfs when the data was collected representing a 97% flow duration or about a 5-year low flow event. Another preferable sampling condition is having no runoff during and prior to the survey. There was no runoff three weeks prior to August 5,6,7 and none during the sampling resulting in ideal conditions. Runoff is undesirable due to the difficulty of quantifying it as input to the model. One of the water quality model's underlying assumptions requires steady state conditions. This would not be met if significant runoff occurred during or two to three days prior to the sampling event.

The 1997 data indicate that minimum statutory dissolved oxygen criteria were met and often greatly exceeded at all locations, except North Lincoln, where minor non-attainment of class B dissolved oxygen criteria sometimes occurred. Of significance, however is the fact that point source discharges were at only 10% of their licensed permitted BOD limits. Hence the potential for lower dissolved oxygen levels than measured is possible, and worse case levels must be determined by the model. The chlorophyll a data was slightly elevated on two impoundments on the West Branch and the lower estuary. This indicates that a eutrophication problem on the Penobscot River may be forthcoming. Data collected by the Penobscot Nation recently has sometimes revealed similar results.

Water Quality Model

The EPA supported model, QUAL2EU was used in the analysis of the Penobscot. Steady state flows and load inputs are required and major transport mechanisms of advection and dispersion must be one-dimensional. The lack of runoff that was previously discussed satisfies the steady state condition. The uniformity of the dissolved oxygen and temperature readings in the vertical profiles indicates that the Penobscot is a well-mixed system and hence one-dimensional flow occurs. The Penobscot River should be well suited to this model.

A change to the computer programming of QUAL2EU was made so that the estuary portion can accurately calculate dissolved oxygen saturation. The former model did not take into account the effect of salinity, which lowers the saturation value as salinity increases. Assistance was provided through a consultant firm that was made available from EPA. Anyone requesting the input to this model should also get copies of the revised estuary version of QUAL2EU (QUAL2EST).

The major change made to the current model from the 1991 effort was the merging of the three separate sections (West Branch, Middle Penobscot, and Lower Penobscot) into one continuous model from Millinocket to Bucksport. QUAL2EU allows up to 250 reaches and point source inputs now, and in comparison, only 20 were formerly allowed. The model now has 39 reaches, and 34 point source inputs (figure 1). (In the model non-point source tributary inputs are modeled as point sources. There were actually 15 point source inputs and 19 tributary inputs.) The estuary was simulated as a tidally averaged steady state model. Algae, nutrients, and salinity were added as systems that were not modeled previously. To account for diurnal variability of dissolved oxygen due to the photosynthesis and respiration of phytoplankton and attached algae, a diurnal adjustment was added to the model. This adjustment is necessary since the model output is a daily average dissolved oxygen and classification criteria are ordinarily expressed as a daily minimum. The diurnal adjustment is subtracted from the model daily average results to obtain the daily minimum (which usually occurs in the early morning). The dissolved oxygen diurnal adjustment was based upon actual field measurements and results and ranged from no adjustment to 0.5 ppm (figure 2).

Model Transport

In the hydraulic component of the model, river velocity and depth relationships are developed as a function of flow. Transect and time of travel data are used as a basis for deriving the relationships. QUAL2EU offers two options for the transport of pollutant parameters; a power equation and the Manning equation for open channel flow. The power equation option was chosen for the Penobscot River model. This computes velocity and depth as a function of flow with the following equation:

$$\mathbf{V = A_1 Q^{B}{}_1 \quad and \quad D = A_2 Q^{B}{}_2}$$

where V = velocity; D = depth; Q = flow, and A_x, B_x are coefficients that are empirically derived from transect and time of travel data

The hydraulic coefficients were already calculated from a previous MDEP modeling effort (see Penobscot River Basin Waste Load Allocation, P. Mitnik, 1991). No changes were made to the 1991 model hydraulic coefficients (table 3).

Dispersion or longitudinal spreading becomes very significant in the estuary and must be appropriately considered. A conservative parameter such as the salinity data is generally used to calibrate the dispersion rates to use in the estuary. Initial estimates of dispersion can be obtained by plotting Ln salinity Vs river mile. The dispersion is then the estuary advective or flushing velocity divided by the slope of the Ln salinity Vs river mile. Initial estimates of dispersion rates used in the estuary ranged from 5 to 75 mi^2/day and resulted in a good fit of the salinity data to measured values (figure 3, 3a, table 4).

Flow data is available at a number of locations throughout the Penobscot River watershed. USGS gages that were used include the Penobscot River at West Enfield; Mattawamkeag River at Mattawamkeag; and Piscataquis River at Medford. Additional river flow information is estimated by Great Northern Paper Co. at Dolby dam, at the mouth of the East Branch of the Penobscot, and Weldon dam. Bangor Hydro Co also provides river flow estimates for the Penobscot at the Milford dam and for the Stillwater River branch of the Penobscot. A flow balance was calculated for the watershed (table 5) using this available flow information and a proration of watershed drainage area for tributary inputs to the Penobscot. The larger tributaries were input to the model as point sources and the smaller tributaries were group as incremental flow inputs or distributed loads.

Chemical Calibration of the Water Quality Model

The 1997 data collected on August 3, 4, and 5 were used to re-calibrate the Penobscot River water quality model. The chemical calibration of the model involves inputting measured tributary and treatment plant effluent as point source loads, measured upstream and downstream boundary conditions and measured water temperature as initial conditions. The model output of various parameters, such as BOD, chlorophyll a, and dissolved oxygen are compared to measured values and adjustments are made to the model parameter rate coefficients until a good match of model and observed data occur. The model parameter rates that are typically adjusted include such items as the BOD removal rate, reaeration rate, algae growth and respiration rates, and, in some cases, the sediment oxygen demand rates. Parameter rates that were calibrated from the 1991 model were initially used, but this resulted in the model dissolved oxygen being consistently higher than the observed 1997 data and the model ultimate BOD being slightly lower than the values measured in 1997. As a result, the following adjustments were made to the model:

- Adjustment of the BOD removal rate to 0.06 per day on all model reaches.
- Inclusion of a non-point BOD as a distributed load input.
- The adjustment of the sediment oxygen demand upward in some model reaches
- The adjustment of the reaeration rate in two reaches
- Inclusion of algae and nutrient parameter rates
- Re- assignment of BODu/BOD5 ratios for municipal effluents based upon 1997 data.

Due to the very low level of ammonia measured in the river, BOD was modeled as total ultimate BOD and not partitioned into the carbonaceous and nitrogenous fractions. Considerable time was spent in the development of the Penobscot River model in the mid-1980's and the BOD removal coefficients formerly calibrated then are believed to be accurate. For this reason, only a minor adjustment was made to the BOD decay coefficient, K_d. K_d was not changed in the majority of the river reaches and only adjusted in some of the reaches on the West Branch that were formerly set at 0.05 per day to 0.06 per day. All reaches are now set at 0.06 per day.

The reason for lower modeled BOD than the observed data is believed to be due primarily to a deficiency in QUAL2E when modeling non-point source inputs. The model does not have a benthic source rate for BOD. When modeling long sections of river this can result in an unrealistic representation of actual conditions, since with a long enough travel time, modeled river BOD values will eventually approach zero. This was compensated for by inputting non-point source BOD into the incremental inflow portion of the model as a distributed load. A value of 30 ppm resulted in a constant total BOD of greater than 3 ppm in all river sections when simulating conditions with no point source inputs. A lower bound of 3 ppm for TBOD is most likely a realistic representation of overall background water quality in the Penobscot River, since tributary and upstream boundaries usually exceed this value. This results in a total NPS load (not including tributary inputs) of 22,400 lb/day of ultimate BOD for the entire river. When the size of the drainage area is considered, this is not a large value. The dissolved oxygen depletion from this load is estimated to be only 0.03 ppm by the model.

The calibration of total ultimate BOD was inexact due to the low input from point sources in the August 1997 data (10% of licensed load) and the large dilution available from the Penobscot River. This results in only minor differences of BOD from station to station, but a downward trend of slightly greater than 1 ppm is observed from Millinocket to Bucksport. The BOD removal rate of 0.06 per day results in a reasonable fit of the model to observed data (see figure).

The calibration of chlorophyll a resulted in a reasonable fit of model output to the observed data in all areas except for the impoundments on the West Branch where observed data is much higher than the model output. The algae growth rate used of 3.0 per day is on the high end of the range specified in the QUAL2E user's manual (1 to 3 per day) as within recommended values. It is not likely that these higher chlorophyll a values could be matched with QUAL2E without using unreasonably high inputs for algae growth. There was a similar occurrence of this situation with the 1985 data on the West Branch. It is possible that a complex phenomena occurs on the West Branch that cannot be simulated with a one dimensional, steady state model. Additional work may be warranted here.

The calibration of dissolved oxygen involved minor adjustments to the reaeration rate, k_a, and the sediment oxygen demand (SOD) rate in some reaches. The O-Connor Dobbins reaeration formula which calculates reaeration as a function of velocity and depth was used in most reaches.

$$\mathbf{k_a = 12.85\ V^{.5}/D^{1.5}}$$ where v = velocity in fps, and D = depth in ft

In the deeper and lower velocity reaches, k_a was calculated by an impoundment reaeration formula which is considered a lower bound for k_a whenever the O Connor-Dobbins formula results in a lower estimate.

$$\mathbf{k_a = 3/D}$$

The parameter rates used for each model reach are summarized in table 6. The calibration of dissolved oxygen with these parameter rates results in a good fit of the model output to measured data. Of the 30 sample locations compared, 14 (47%) and 24 (80%) were within 0.1 and 0.2 ppm, respectively, of the observed data. The largest difference between modeled and observed was 0.4 ppm at two locations.

The model calibration ordinarily involves verification with a second independent data set. A second three-day data set was not collected in 1997 and for this reason the update of the model is considered incomplete. An additional three-day data set is recommended for the next year MDEP is scheduled to be in the Penobscot River watershed, which is the summer of 2001. Since only minor adjustments were made to the modeling effort of 1991, the model is verified with the older data and prediction runs can still be made. The data to be collected two years from now will further improve the model accuracy and continue to illustrate trends in water quality on the Penobscot River.

Model Predictions Runs at 10-Year Low Flow

After the water quality model is calibrated to observed data, a prediction run is made at worst case conditions to assure dissolved oxygen criteria will be achieved at all locations. Worse case conditions are defined by low river flows, when dilution of wastewater is at a minimum; by high water temperatures, when the saturation of dissolved oxygen is lower and BOD decay and oxygen demand from the sediment are higher; and by point sources discharging at licensed limits. Non- point source loads are accounted for as tributary loads with pollution concentrations as measured in the August 1997 survey, distributed load inputs in the model incremental flow, and as sediment oxygen demand (which results partially as sediment that has settled during runoff events prior to low flow).

Two tests are run with the water quality model to check dissolved oxygen compliance with statutory criteria; one to test compliance of minimum dissolved oxygen criteria and a second to test compliance with the monthly average criteria of 6.5 ppm. Temperatures in the riverine portion of the model of 24 ^{o}C and 22^{o}C, respectively were assumed for the two predictions run tests. In the first test assessing compliance with minimum dissolved oxygen criteria, the 7 day 10 year low flow (7Q10) is used as the river design flow and point sources are inputted at their weekly average licensed loads. Since the paper mill licenses have no weekly average BOD5 on their permit, ratios of weekly average to daily maximums were derived, based on three years of discharge monitoring data provided by the mill personnel. The second test assessing compliance with monthly average dissolved oxygen criteria involves the use of a 30 day 10 year low flow (30Q10) and point sources are inputted at monthly average licensed BOD loads. In both these runs, pollutants that are not included in the license such as nitrogen or phosphorus are ordinarily inputted as measured in the calibration data (August 1997). The ultimate point source BOD must be derived from the product of a BODu/BOD5 ratio (which is derived from data) and the licensed BOD5 concentration. Point source inputs to the model and related information is summarized in table 7.

The classification of the Penobscot River changes from B to C in the riverine portion and is classified SC in the estuarine portion of the river. The following five segments define its classification:

1. From the Ferguson Lake outlet to the Mattawamkeag River – Class C
2. From the Mattawamkeag River to 1 mile above the West Enfield Dam – Class B
3. From 1 mile above the West Enfield Dam to the West Enfield Dam– Class C
4. From the West Enfield Dam to Reed Brook in Hampden – Class B
5. From Reeds Brook to Bucksport – Class SC

The dissolved oxygen criteria is as follows:

Class B	Daily minimum $\geq$ 7.0 ppm and 75% of saturation
Class C	Daily minimum $\geq$ 5.0 ppm and 60% of sat.; monthly average $\geq$ 6.5 ppm
Class SC	Daily minimum > 70% of saturation

The model prediction run at 7Q10 flow indicates that minimum dissolved oxygen criteria will be met everywhere except the following (figure 7):

1. An eight-mile class B segment from Winn to North Lincoln in which levels not lower than 6.6 ppm (0.4 ppm under class B criteria) are predicted. Dissolved oxygen levels

0.3 ppm under the class B criteria were also measured in the 1997 data at the North Lincoln site.

2. A five-mile segment from the West Enfield dam to Passadumkeag that is within 0.1 ppm of class B minimum criteria. The model calibration of dissolved oxygen was 0.2 ppm low at Passadumkeag and measurement error of dissolved oxygen is about 0.2 ppm. Since the predicted model non-attainment is less than the calibration and measurement error, this segment can be considered to be marginally attaining dissolved oxygen criteria.
3. A one- mile segment at the end of the tidal river in Orrington, where the model predictions of dissolved oxygen are within 0.1 ppm of minimum class B criteria. This is within measurement error and can be considered a marginal attainment of dissolved oxygen criteria.

The model prediction run at 30 Q10 flow to check compliance with monthly average dissolved oxygen criteria indicates that criteria will be met everywhere reaching a low of 6.6 ppm below the Rockabema dam above the confluence to the East Branch of the Penobscot (figures 8a, 8b).

Sensitivity Analysis

In a sensitivity analysis, some of the parameter rates can be tested to determine which are more important in the development of the model. The August 1997 data set was used as a basis for the sensitivity analysis runs. Each parameter was multiplied by a factor of 0.5 and 2 and the model output for dissolved oxygen and chlorophyll a was then compared to the original model result (table 8). The sensitivity analysis is further summarized as bar column plots, which show the relative difference in dissolved oxygen (figure 9) at some sample locations for the parameter rate multipliers of 0.5 and 2.0. From this analysis it appears that the most important items in the calibration of the model dissolved oxygen is the atmospheric reaeration rate, followed by the sediment oxygen demand rate. The BOD decay rate was the least sensitive parameter of the three tested.

Component Analysis

In the component analysis, potential factors to water quality degradation are individually subtracted from the model and the difference in dissolved oxygen in then observed. The relative contribution of various factors to dissolved oxygen depletion in the water body can then be determined. The component analysis is displayed as a series of pie chart percentage comparisons (figures 10 - 12). The model prediction run at 7Q10 flow was used as a basis for the component analysis.

The component analysis of the dissolved oxygen deficit is analyzed at three strategic locations; above the Rockabema dam (DO sag point on the West Branch); Winn (point of maximum D.O. non-compliance), and Orrington (DO sag point in tidal waters). (The DO sag point is defined as the point of minimum dissolved oxygen below a discharge or series of discharges. It is ordinarily used a regulatory compliance point, since meeting D.O. criteria here, guarantees compliance everywhere in the river.)

Five components of dissolved oxygen depletion were investigated

1. Sediment oxygen Demand (SOD) – Includes all SOD collectively from natural, point source, and non-point sources.
2. Point Source BOD – Includes nitrogenous and carbonaceous BOD from all industrial and municipal sources.
3. Non-point Source BOD - Includes nitrogenous and carbonaceous BOD from tributary and incremental drainage.
4. Background – Model run with no background impact. Dissolved Oxygen is adjusted to 100% saturation and background BOD is adjusted to zero. Collectively includes the natural DO deficit and background BOD impacts from non-point sources.
5. Nutrients – Diurnal dissolved oxygen impacts from attached and floating algae. Includes nutrient impacts from point source, non-point source, and natural.

Above the Rockabema dam (figure 10a), sediment oxygen demand and background conditions are the largest factors contributing to dissolved oxygen depletion resulting in about 38% and 32% of the total D.O. deficit, respectively. Point source BOD is responsible for about 20% of the total dissolved oxygen depletion. Nutrients and non-point source BOD are unimportant, contributing about 9% and 1%, respectively to the total dissolved oxygen deficit.

At Winn (figure 10b), sediment oxygen demand and nutrients are the largest factors contributing to dissolved oxygen depletion and result in about 35% and 28% of the total D.O. deficit, respectively. Point source BOD and background conditions are each responsible for about 17% of the total D.O. deficit. Non-point source BOD is unimportant and results in only about 3% of the total D.O. deficit.

At Orrington (figure 10c), sediment oxygen demand and point source BOD are the largest factors contributing to dissolved oxygen depletion and result in about 38% and 35% of the total D.O. deficit, respectively. Non-point source BOD and background conditions are responsible for about 16% and 11%, respectively, of the total D.O. deficit. Nutrients are unimportant and results in no effect on D.O. depletion.

Nutrient loads are also calculated and their relative contribution compared on pie chart diagrams (figures11a, b, 12). This analysis indicates which inputs may be the most responsible for nutrient related dissolved oxygen depletions, although the load percentages are not necessarily proportional to the dissolved oxygen depletion. On the West Branch, the nutrient loads from the two Great Northern Paper Mills are the largest source of phosphorus, accounting for nearly 70% of the total phosphorus load at low flow conditions (figure 11a). On the lower Penobscot River, the city of Bangor is the largest source of nutrients at low flow conditions, accounting for about 50% of the total phosphorus and more than 60% of the total dissolved nitrogen (figures 11b, 12).

Discussion

From a regulatory perspective, cleanup action is needed on the river above Winn. There is an eight-mile segment projected by the model to be in non-attainment of minimum class B D.O. criteria of 7.0 ppm. The non-attainment is not serious, but an additional 0.4 ppm of D.O. must be gained to meet minimum criteria. The water quality modeling is not yet complete. The quality of the August 1997 data set is good and serves a sound basis for model calibration. An additional data set is needed to “verify” the model. The algae component of the model needs additional work, in particular, on the impoundments on the West Branch where the model’s prediction of chlorophyll a levels was consistently low.

Control of BOD and phosphorus are investigated as a method of improving the dissolved oxygen levels in the eight-mile non-attainment river segment. Phosphorus is the limiting nutrient responsible for the growth of benthic algae and phytoplankton (floating algae). Limiting phosphorus inputs to the river will limit algae production, which will also alleviate the early morning low dissolved oxygen readings that result from extended evening respiration. The algae typically produce excess oxygen when exposed to light during the daytime through photosynthesis, and the maximum daily dissolved oxygen is reached at mid to late afternoon. Conversely, at night in the absence of light, extended respiration results in a continuing depletion of dissolved oxygen until minimum daily values are achieved at dawn.

The model prediction estimate that Great Northern Paper mills are responsible for about 0.3 ppm of the dissolved oxygen depletion at Winn. Hence even very strict BOD reductions here will not result in eliminating all of the D.O. non-attainment. Nutrients are the largest controllable source that could result in direct improvements at Winn and collectively are responsible for about 0.5 ppm of the D.O. depletion. The Great Northern Paper Mills are responsible for about 70% of the phosphorus loads on the Penobscot above Winn, including the West Branch.

Phosphorus is often added to paper mill effluent to facilitate BOD removal. It is suggested as an interim measure, that pollution prevention measures be encouraged to optimize phosphorus addition. The goal of this would be adding just enough phosphorus to facilitate BOD removal, but at the same time continuously adjusting the amount of phosphorus added to eliminate excess amounts.

Collection of an additional data set for model verification is scheduled for the summer of 2001. After this data is collected, additional time could be spent, in particular, on the algae component of the model. The data would document improvements in D.O., should they exist, as a result of the recommended pollution prevention measures. If non-compliance of class B D.O. criteria still results, a model prediction run with the necessary nutrient reductions should then be made.

It is also suggested that other point sources consider voluntary pollution prevention measures to reduce nutrients. For non-tidal waters, this would mean phosphorus reductions; and for tidal waters nitrogen reductions for both ammonia nitrogen and nitrate nitrogen. The marginal compliance of class B D.O. criteria in two locations and the slightly elevated chlorophyll a in the estuary are still reason for concern. There is currently very little, if any, assimilative capacity remaining in the river. Although no license restrictions are currently necessary, voluntary pollution prevention measures to reduce nutrients could result in delaying or possibly eliminating the need for mandatory license nutrient limits in the future. It could also result in freeing up some assimilative capacity that would otherwise result in requirements for advanced waste treatment as city and towns in this watershed continue to grow.

Responses to Comments

Responses to Bangor WWTP

1. *Explanation of testing that was done to determine Bangor's pollutant loads to river and how non-point source loads were accounted for.*
Response: The testing that was done is explained in detail in the Penobscot River Data Report (MDEP, April 1998). Eleven locations on the river, six locations in tidal waters, ten tributary sites, and fifteen point sources were sampled for BOD, nutrients, and chlorophyll a. A flow balance of the watershed was setup up with gaging information. Both point and non-point loads could be directly calculated with flow and pollutant concentration information.

2. *Highlight strengths and weaknesses of QUAL2EU model.*

Strength*s*

· Calibration data set sampled in August of 1997 is considered excellent data. The data was collected at a very flow and no runoff occurred three weeks prior to the survey. Good QA / QC procedures were followed.

· The QUAL2EU model underlying assumption of steady state and one-dimensional flow are well suited to the Penobscot River.

· Good estimates of point source and non-point source pollutant loads experienced on the Penobscot during drought flow conditions could be provided.

· A good calibration of BOD and dissolved oxygen was achieved.

Weaknesses

· No verification data set is available. This data will tentatively be collected in the summer of 2001.

· The calibration of chlorophyll a resulted in lower model algae than measured on some of the West Branch impoundments. Additional work on the algae component of the model is needed. Episodic algae blooms have been reported by the Penobscot Nation's data. The frequency of eutrophication on the Penobscot as a problem needs to be established.

• Sediment oxygen demand was not measured. The sources of SOD also need to be estimated. This data is scheduled for collection in 2001.

Great Northern Paper Comments

GNP objects to “mandatory” phosphorus reductions through pollution prevention recommended for their East Millinocket mill.
Response: DEP agrees that GNP has demonstrated a willingness to exceed requirements dictated by environmental laws. This is evident in their immediate success in voluntarily reducing phosphorus at their East Millinocket Mill. “Mandatory” will be changed to “voluntary” in the text of the modeling report.

Figures and Tables